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SITE INVESTIGATIONS AND PLANNING FOR TUNNELS IN GRANITE

- What is granite
- Site investigations
- Geotechnical design principles

GRANITE is a plutonic rock consisting of alkali feldspars and quartz + minor contents of mica. The rock is coarse grained and homogenous.
• Granite is normally a strong and hard rock and the word “granite” is therefore often used by rock engineers as the common word for hard and strong rocks, thus including other plutonic, coarse grained rocks as well as granitic gneisses.

• This is the way the word granite will be used in this presentation.

Gabbro
Weathering of granite in Singapore

Weathering of granite in Kenya
Weathered granite

Exfoliation in granite,
Fyresdal, Norway
Exfoliation in granite, Fyresdal, Norway

Shear stress as a function of shear displacement with varying normal stress
The main goals for the geotechnical site investigations for tunnels are to obtain:

• The necessary input for the evaluation of site and alignment alternatives for the overall planning of a project.

• A basis for evaluation of potential stability problems and the necessary input parameters for stability analyses and planning of rock support.

• A basis for cost evaluation and for preparation of tender documents.

INVESTIGATION STAGES

• Preconstruction phase investigations
  Underground works have not yet started and all information has to be collected on or from the surface.
  1. Feasibility study exploration
  2. Definite plan study investigations

• Construction phase investigations
  Through tunnels being excavated the rock masses are accessible for inspections and sampling.
  3. Detailed subsurface investigations
  4. Tunnel mapping
1. Feasibility study exploration

Desk studies of:
• Geotechnical literature
• Topography and geological maps
• Aerial photos

Walk-over survey for preliminary mapping of soil cover, rocks, jointing and weakness zones.

Investigations at key points for tunnels:
• Entrances
• Areas of small rock cover
• Check of soil thickness in critical points

Feasibility study report

• review of geological and geotechnical conditions
• evaluation of feasibility for different alternatives
• plan and cost estimate for detailed investigations
• need for more maps and aerial photos
2. Definite plan study investigations

Engineering geological mapping along tunnel alignment:
• types and quality of rocks
• orientation, spacing and character of joints
• orientation, thickness and type of weakness zones
• ground water condition
• rock stress conditions

Special investigations:
• geophysical investigations (refraction seismic survey)
• core drilling

Sampling and laboratory testing of rocks:
• Strength, drillability, blastability

Definite plan study report

• Descriptions (with maps and cross sections) of all topographical and geological factors that may influence construction and use of tunnels and openings

• estimates and preliminary plans for excavation requirements, rock sup-port and lining

• plans for use of rock material
3. Detailed subsurface investigations

**Sampling and testing** of rocks and infilling (gouge) materials from joints and faults.

**Supplementary investigations:**
- rock stress measurements
- permeability tests of rock masses
- convergence measurements of openings
- control and revision of reports from preconstruction phase investigations.

**Recommendations** of permanent rock support and lining, for grouting and for excavation through highly unstable rock masses.

Subsurface investigation reports

- Supplementary reports from construction phase investigations.
- Report on permanent rock support and lining.
4. TUNNEL MAPPING

Mapping in tunnel of:
- types and quality of rocks
- orientation, spacing and character of joints
- orientation, thickness and type of weakness zones
- water seepage
- stress induced problems

Registration of all rock support, lining and rock improvement.

Evaluation of excavation performance.

Tunnel mapping report

- Final report with tunnel map and review of rock support.
- Evaluation of preconstruction phase investigations.
Weakness zones exposed in the terrain

Weakness zone
Weakness zone in precambrian gneiss

Fall-outs from a weakness zone in a tunnel
Air photo showing outcropping of weakness zones

Geological soil map indicating outcropping of weakness zones
Dipping of planar weakness zones

Design of weakness zones on topographical map -1
Design of weakness zones on topographical map -2

Design of weakness zones on topographical map -3
DESIGN APPROACH OF UNDERGROUND OPENINGS

MAIN PRINCIPLES FOR ENGINEERING GEOLOGICAL DESIGN

SHALLOW-SEATED AND DEEP-SEATED OPENINGS

SITE SELECTION

ORIENTATION OF LENGTH AXIS

SHAPING OF CAVERNS

DIMENSIONING OF CAVERNS

EXAMPLES OF THE USE OF THE UNDERGROUND

General planning and design procedure for underground openings

1. A location representing the optimum rock stability condition is selected

2. The length axis of the cavern is oriented so that overbreak and stability problems are minimized.

3. Caverns and tunnels are shaped in accordance with the material properties and the jointing of the rock mass

4. The various parts are dimensioned to give an optimum economic result
SHALLOW-SEATED AND DEEP-SEATED OPENINGS

• Shallow-seated openings
  short distance to the surface combined with low stresses in the rock mass. Interlocking effect between the rock blocks is reduced. Reduced arching effect.

• Deep-seated openings
  in rock masses where the stress level may locally exceed the strength of the rock. This may cause rock bursting or squeezing.

Necessary rock overburden for shallow-seated openings
Location of tunnels or caverns in a high valley side with weakness zone
A: Destressed area – no rock bursting.
B: Highly anisotropic stress situation – intensive rock bursting
C: Normal stress situation - moderate rock bursting.

Joint rosette for evaluation of the orientation of a rock cavern
Location and orientation of caverns based on topographical and geological conditions

Arrows are pointing at places of instabil rock masses due to lack of compressive stresses
ROCK BURSTS IN GRANITE

Indications of areas prone to rock bursting problems for various orientations of the major principal stress
Principle for shaping of caverns with varying stress level and orientation of the major principal stress.

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<th>STRESS LEVEL</th>
<th>DIRECTION OF MAJOR PRINCIPLE STRESS</th>
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<td>Even distribution</td>
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<td>Assymetric profile</td>
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Reduced effective wall thickness between to caverns due to the jointing of the rock mass
USE OF THE UNDEGROUND

• Industrial installations like powerhouses, factories, telecommunication centres.

• Municipal installations like treatment plants for drinking water and sewage, and car parks.

• Storing of food, water, oil, pressurised gas, industrial waste and several other products.

• Entertainment and recreation like sports halls, swimming pools, art centres, theatres, etc.

• War protection - Air raid shelters.

Modern underground hydropower station – Åna-Sira
Water supply and sewage treatment system in Trondheim

Inside water storage cavern, Steinan, Trondheim
Underground sewage treatment plant, Høvringen, Trondheim

Oset underground water treatment plant, Oslo
Underground deep freeze storage, - temperature – 25-30 oC

Oil storage cavern, Gothenburg, Sweden
Swimming pool and sports hall at Holmlia, Oslo

Swimming pool at Holmlia, Oslo
Sports hall at Holmlia, Oslo

Underground caverns at Gjøvik:

(1) The Olympic mountain hall

(2) Swimming pool

(3) Telecommunication centre

(4) Civil defence authorities
Gjøvik Olympic Mountain Hall during construction

Width: 61 m
Height: 25 m
Length: 91 m

Rock overburden: 25 – 50 m
Gjøvik Olympic Mountain Hall